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Brief article

Newborns' face recognition is based on spatial frequencies below 0.5 cycles per degree

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Abstract

A critical question in Cognitive Science concerns how knowledge of specific domains emerges during development. Here we examined how limitations of the visual system during the first days of life may shape subsequent development of face processing abilities. By manipulating the bands of spatial frequencies of face images, we investigated what is the nature of the visual information that newborn infants rely on to perform face recognition. Newborns were able to extract from a face the visual information lying from 0 to 1 cpd (Experiment 1), but only a narrower 0–0.5 cpd spatial frequency range was successful to accomplish face recognition (Experiment 2). These results provide the first empirical support of a low spatial frequency advantage in individual face recognition at birth and suggest that early in life low-level, non-specific perceptual constraints affect the development of the face processing system.

Keywords: Development; Newborns; Face processing; Spatial frequencies

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1. Introduction

A central issue in Cognitive Science is how knowledge of specific domains emerges during development. Faces represent a paradigmatic class of stimuli to address the development of specialized cognitive functions, because several lines of evidence raised the possibility that face processing in adults involves domain-specific processes carried out by dedicated brain areas (e.g. Kanwisher, 2000).

Faces are highly salient and biologically significant visual stimuli that provide critical cognitive and social information since birth. Newborns possess face recognition skills despite limited visual abilities and immature cortical visual areas. They discriminate their mother's face from a female unfamiliar face (e.g. Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995), and recognize unknown faces to which they have been habituated (Pascalis & de Schonen, 1994; Turati, Macchi Cassia, Simion, & Leo, 2006). Yet, despite convergent evidence on newborns' ability to learn and discriminate individual faces, little is known about the kind of visual information newborns' face recognition relies on.

Some studies on adults' face processing have explored the role of low-level visual information, and particularly of the spatial frequency content of the stimulus, in driving face recognition. Spatial frequency is a characteristic of any structure that is periodic across position in space, and a measure of how often the structure repeats per unit of distance. In the study of visual perception, spatial frequencies (SF) are thought to convey different types of information for visual processing: low spatial frequencies (LSF) represent large-scale variations of luminance changes (coarse visual information), whereas high spatial frequencies (HSF) represent tighter gradients (fine visual information). Marr (1982) postulated that the operation of spatial frequency channels is part of the bottom-up processing of retinal image and that information about spatial frequency content is not retained at higher levels of visual processing. Conversely, Ginsburg (1986) and Sergent (1986) proposed that different spatial frequency bands supply differentially high-level perceptual functions. As stimuli are passed through banks of filters, a certain perceptual organization of a visual pattern emerges, and, in turn, affects subsequent high-level visual processes of the stimulus. Along these lines, it has been examined whether there are bands of frequencies that most effectively carry information about face identity. Evidence showed that face recognition relies optimally on an intermediate band of spatial frequency (e.g. Näsänen, 1999, but see Liu, Collin, Rainville, & Chaudhuri, 2000) and putted forward the appealing possibility that the configuration of a visual face stimulus is largely subtended by coarse information, as provided by LSF (Goffaux & Rossion, 2006; Goffaux, Hault, Michel, Vuong, & Rossion, 2005; Morrisson & Schyns, 2001). Spatial filtering is therefore generally considered as an early stage of visual processing, the outputs of which form a basis for higher level operations, such as recognition.

Given this evidence in adults, one may wonder what critical bands of spatial frequencies are crucially involved in newborns' face recognition. Newborns' visual sensitivity is limited, in particular to certain spatial frequency ranges. This limitation is represented by the newborns' contrast sensitivity function (CSF, Acerra, Burnod, & de Schonen, 2002; Banks & Bennett, 1991) that summarizes the functional properties

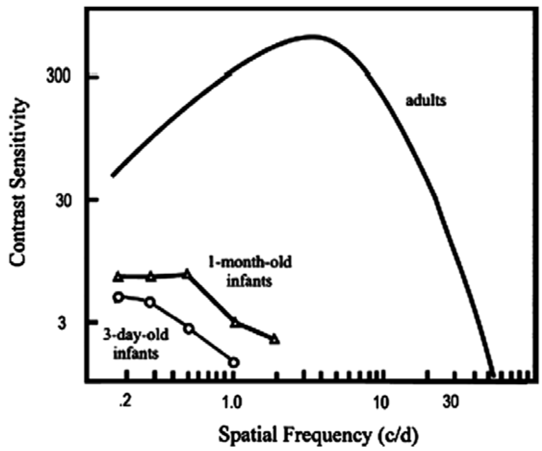

Fig. 1. Contrast sensitivity function (CSF) for adults, 1-month-old infants (Banks & Salapatek, 1978) and newborns (Acerra et al., 2002). c/d = cycle per degree.

of the visual system at birth. Newborns' visual acuity is 40 times worse than that of a normal adult, because at birth infants are unable to process spatial frequencies greater than 1 cpd (cycle per degree). Also, newborns are about 30 times less sensitive to contrast than adults, with peak sensitivity between 0.1 and 0.2 cpd (Slater & Sykes, 1977). Compared to adults' CSF, newborns' CSF appears shifted downward and leftward, underlying the importance of LSF to process and recognize visual stimuli early in life (Fig. 1).

Several authors have raised the hypothesis that infants' limited visual capacities play a role in shaping the developing face processing system in the first year of life (de Schonen & Mathivet, 1989; Le Grand, Mondloch, Maurer, & Brent, 2001). However, this proposal has never been explored by testing what are the bands of spatial frequencies the infants' visual system rely upon for the identification of faces.

Here we aimed at investigating what is the nature of the visual information that newborns rely on to perform face recognition, by manipulating the bands of spatial frequencies of face stimuli. In Experiment 1, stimuli were filtered to reveal spatial information either greater (>1 cpd filtering) or smaller (<1 cpd filtering) than 1 cpd, i.e. at the threshold of newborns' visual acuity (e.g. Acerra et al., 2002). Gaussian filters that reveal little spatial information greater (between 0.5 and 1 cpd) or smaller (<0.5 cpd filtering) than 0.5 cpd were chosen in Experiment 2 so that both the LSF and the HSF versions of the stimuli contained half of the frequencies comprised in the range to which the newborns' visual system is sensitive.

2. Experiment 1

Using a cutoff point at 1 cpd, Experiment 1 aimed to determine whether the band of spatial frequencies available to newborns for face recognition does not exceed the limit predicted by their CSF (1 cpd). We predicted that, after being habituated to a filtered face, newborns would show a preference for novelty when the available band of spatial frequencies correspond to their visible range (LSF condition) but not when spatial frequencies exceed this range (HSF condition).

2.1. Method

2.1.1. Participants

Thirty-five healthy, full-term newborns were selected from the maternity ward of the Pediatric Clinic of the University of Padua. Seven participants did not complete testing because of fussiness or drowsiness, and one showed a position bias during the preference test phase. The final sample consisted of 28 newborns (mean age: 49.75 h, normal delivery, weight between 2295 and 4080 g) randomly assigned to LSF or HSF condition.

2.1.2. Stimuli

Stimuli were filtered images extracted from four high-quality photographs of real female faces subtending 24° of visual angle horizontally and 34° vertically. Original faces were Fourier transformed and dot multiplied by lowpass and highpass Gaussian filters to preserve low (<1 cpd filtering, std = 0.85 cpd) or high (>1 cpd filtering, std = 0.85 cpd) spatial frequencies, respectively (Fig. 2). The mean luminance of face images in the LSF and HSF conditions was comparable (17.41 and 15.54 cd/m^2, respectively).

2.1.3. Procedure

An infant-controlled habituation procedure was used. Newborns were placed at a distance of 30 cm from a screen. Their eyes were aligned with a red flickering light-emitting diode (LED) used to attract their gaze at the beginning of both the habituation and the preference test phases. In the habituation phase, a filtered face was projected bilaterally, to the left and the right of the central LED. Stimuli remained on the screen until the habituation criterion was reached; that is when the sum of any three consecutive fixations was 50% or less than the total of the first three (Slater, Morison, & Rose, 1983). As soon as the infant's gaze was realigned to the central LED, a preference test phase started with the simultaneous presentation of the face image to which newborns were habituated and a novel face image retaining the same range of spatial frequencies. Each infant was given two paired presentations of the test stimuli, in which the left-right stimulus position was reversed. Each presentation lasted when a total of 20 s of looking to the novel and/or familiar stimuli had been accumulated. An experimenter recorded on-line the duration of infant's fixations on each stimulus. Testing sessions were video-recorded and subsequently codified by a different observer unaware of the stimuli presented. The mean estimate of reliability between observers was 0.99 (Pearson correlation; $p = .01$) for the LSF condition and 0.94 (Pearson correlation; $p = .017$) for the HSF condition.

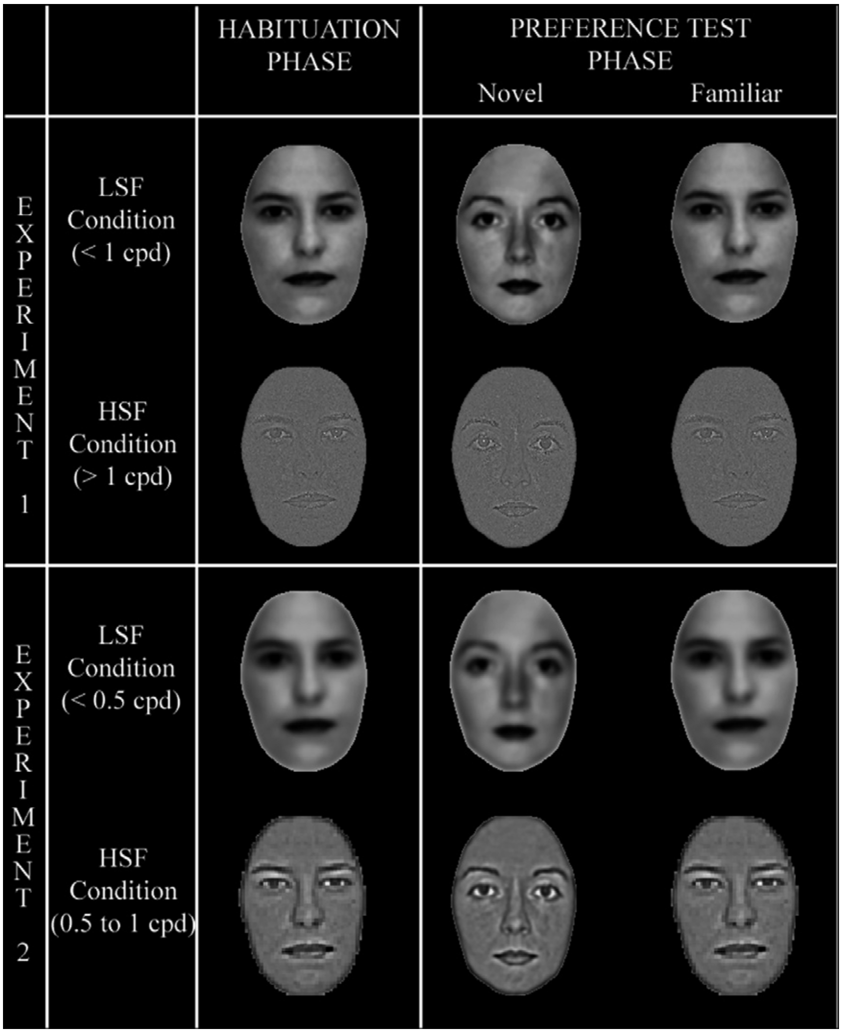

Fig. 2. Examples of stimuli used in Experiments 1 and 2 during the habituation and test phases.

2.2. Results

The average total fixation times during the habituation phase in the LSF (70.15 s, $SD = 27.93$) and in the HSF condition (55.1 s, $SD = 19.65$) did not differ significantly, $t(26) = 1.652$, $p = .11$. To determine whether newborns were able to recognize the filtered face images, a novelty preference score was computed for each infant. In the LSF condition, the preference score for the novel stimulus retaining all the frequencies below 1 cpd was above chance ($M = 62\%$, $SD = 11$, one-sample $t(13) = 4.15$, $p = .001$), what was not the case in the HSF condition ($M = 49.8\%$, $SD = 17.4$, one-sample $t(13) = .049$, $p = .961$). The preference scores obtained in the LSF and HSF conditions were significantly different, $t(26) = 2.276$, $p = .031$.

2.3. Discussion

Newborns discriminate and recognize images of unfamiliar faces to which they were habituated, but only when the spatial frequency range is comprised between 0 and 1 cpd (LSF condition). Therefore, the band of spatial frequencies available to newborns for face recognition overlaps that available for the processing of other non-face visual stimuli (i.e. gratings), as it is represented by the newborns' CSF (e.g. Acerra et al., 2002). Moreover, if considering that HSF provide information related to fine edges of a pattern while LSF support the extraction of coarse cues, outcomes provided indicated that coarse scales play a major role in supplying newborns' visual system with effective information for face recognition. Conversely, fine local details of a face are not sufficient cues for newborns' face recognition; even though one cannot exclude that they are helpful for face recognition when combined with coarse cues.

3. Experiment 2

Experiment 1 shed light on the visuo-perceptual information of a face that is available for face recognition a few days from birth. However, such evidence does not clarify whether there are bands of spatial frequency, *within* the range that is visible to newborns that most effectively carry information about the identity of a face. As observed in adults, one may hypothesize that newborns might be able to detect and process a certain range of spatial frequencies, but use a narrower range in order to perform effective face recognition.

Experiment 2 aimed at determining which bands of spatial frequencies, in the range to which the visual system at birth is sensitive (0–1 cpd), provide the critical source of information that allows newborns to learn and recognize a face. To this end, face images were filtered using a 0.5 cpd cutoff, so that both the LSF (<0.5 cpd) and the HSF (between 0.5 and 1 cpd) versions of the stimuli contained half of the frequencies available to newborns. Moreover, choosing a cutoff of 0.5 cpd ensured that both the LSF and the HSF face images would be detected by newborns, since an identical cutoff was used in a previous study that demonstrated newborns' ability to discriminate local information in LSF and HSF geometric stimuli filtered with the same criteria (LSF filtering <0.5 cpd, and HSF filtering from 0.5 to 1 cpd) (Macchi Cassia, Simion, Milani, & Umiltà, 2002).

Poor visual acuity may prevent newborns from recognizing a face image relying on a range of spatial frequencies narrower than that, already limited, available at birth. According to this hypothesis, one would expect that newborns would not be able to recognize a face either in the LSF or in the HSF condition, because both conditions provide newborns with insufficient cues for recognition. Alternatively, few-day-old infants might be able to learn and recognize a face in the LSF

(Slater & Sykes, 1977), but not in the HSF condition. If so, their performance would characterize a LSF advantage within the newborns' sensitive spatial frequency domain. This would indicate that, within the range of visuo-perceptual information that newborns are able to detect and process, only coarser visual cues act as effective indexes for face recognition.

3.1. Method

3.1.1. Participants

Nine infants were excluded: five showed a position bias and 4 changed states. The final sample consisted of 25 healthy, full-term newborns (mean age: 52 h, normal delivery, weight between 3000 and 4380 g) randomly assigned to LSF or HSF condition.

3.1.2. Stimuli and procedure

As in Experiment 1, stimuli were extracted from four different face images. Each face was filtered using either a Gaussian filter (<0.5 cpd filtering, std = 0.42 cpd), or two Gaussian filters, one low-pass (<1 cpd filtering, std = 0.42 cpd) and one high-pass (>0.5 cpd, std = 0.85 cpd) (Fig. 2). The mean luminance of face images was 22.37 cd/m^2 in the LSF and 20.89 cd/m^2 in the HSF condition. Procedure was the same used in Experiment 1. Inter-coder correlation was 0.94 (Pearson correlation; $p = .03$) for LSF condition and 0.97 (Pearson correlation; $p = .014$) for HSF condition.

3.2. Results

Total fixation time to reach the habituation criterion was not significantly different in the HSF ($M = 62.67$ s, $SD = 22.84$) and LSF ($M = 48.2$ s, $SD = 18.52$) conditions, $t(23) = 1.731$, $p = .097$. A mean novelty preference score significantly higher than the chance level was obtained when newborns had to recognize the LSF face (<0.5 cpd) ($M = 63\%$, $SD = 11$, one-sample $t(11) = 3.995$, $p = .002$). Yet, the *t*-test comparison was not significant in the HSF condition ($M = 48\%$, $SD = 14$, one-sample $t(12) = .501$, $p = .626$). LSF and HSF preference scores differed significantly, independent samples *t*-test: $t(23) = .706$, $p = .008$.

An ANOVA on infants' total fixation time to reach the habituation criterion was run to compare Experiments 1 and 2 and revealed the presence of main effects neither for the cutoff factor (0.5 cpd vs. 1 cpd; $F_{1,49} = .002$, $p = .961$) nor for the band of spatial frequencies (LSF vs. HSF; $F_{1,49} = 1.321$, $p = .256$). However, the interaction between the two factors was significant ($F_{1,49} = 5.602$, $p = .022$) (Fig. 3). Post hoc *t*-tests indicated that newborns' total habituation time was significantly longer in the LSF condition with a cutoff of 1 cpd ($M = 70.15$ s) than in the LSF condition with a cutoff of 0.5 cpd ($M = 48.2$ s), $t(24) = .076$, $p = .029$. An ANOVA run on novelty percentage scores obtained in both experiments revealed a main effect for the factor band of spatial frequencies ($F_{1,49} = 13.226$, $p = .001$), but not for the cutoff factor ($F_{1,49} = .014$, $p = .906$) (Fig. 4).

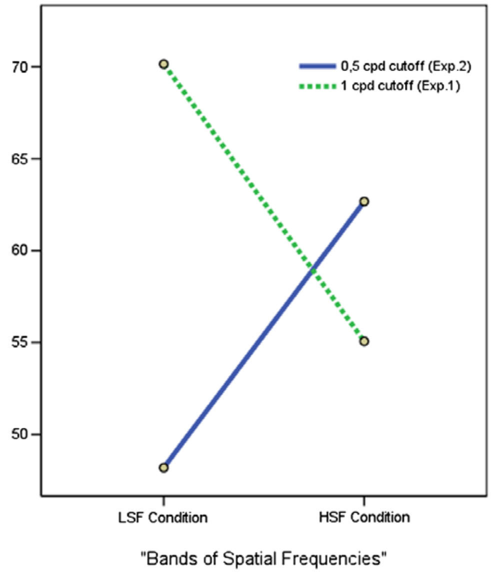

Fig. 3. Time (s) to habituate to filtered faces in Experiments 1 and 2.

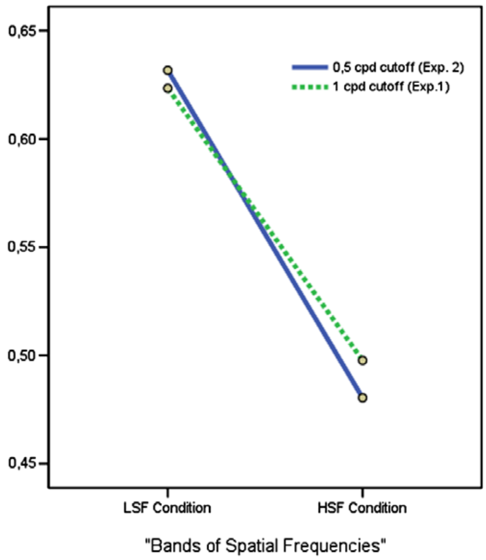

Fig. 4. Percentages (%) of preference for Novelty in Experiments 1 and 2.

3.3. Discussion

Evidence from Experiment 2 demonstrated that individual face recognition depends on the LSF content of the stimuli (0–0.5 cpd). Following the selective removal of the LSF information, face recognition ability vanished. Conversely, selective removal of the HSF (0.5–1 cpd) content did not disrupt newborns' preference for the novel face.

Furthermore, newborns habituated in a significantly longer time to the LSF face whose range lies from 0 to 1 cpd than to the LSF face lying from 0 to 0.5 cpd. These results are in line with evidence on early visual memory that stipulates that in infancy the time needed to habituate to a visual stimulus increases with the complexity of the pattern (Cohen, 1988; Slater & Morison, 1991). The SF range newborns have to process is twice larger in the 0–1 cpd LSF condition (Experiment 1) as compared to the 0–0.5 cpd LSF condition (Experiment 2). Newborns' longer habituation times in the LSF condition of Experiment 1 corroborates the contention that newborns are able to detect and process the visual information comprised in the SF range between 0.5 and 1 cpd (Macchi Cassia et al., 2002), since this range in our face images produced an increased habituation time. Nevertheless, novelty preference scores showed that newborns did not take any advantage from this range in the test phase.

4. General discussion

In line with the CSF for 3-day-old infants simulated by Acerra et al. (2002) and with newborns' visual responses to gratings (Morison & Slater, 1985; Slater et al., 1977, 1985), obtained evidence demonstrated that newborns extract from a face the visual information contained in the LSF range comprised between 0 and 1 cpd. Importantly, within the newborns' sensitive spatial frequency bandwidth, only a narrower range lying between 0 and 0.5 cpd appears to be successful to accomplish the recognition of an individual face. Interestingly, the same SF range was proved to be critical to observe a perceptual dominance of global over local visual information in geometrical hierarchical patterns in newborns (Macchi Cassia et al., 2002), similar to that observed in adults (Navon, 1977).

Here we provide the first direct demonstration that, within the visible range of spatial frequencies, only the extreme low SF range appears useful for newborns' face recognition process. The fact that high-level visual processing of a face is constrained by the operation of low-level spatial frequency filters (Ginsburg, 1986; Morrisson & Schyns, 2001; Sergent, 1986) is very interesting from a developmental point of view, because the low-level characteristics of the visual processing system at a certain age may affect the way in which higher level operations take place and in turn the way in which perceptual development proceeds. Accordingly, the face recognition system may progressively stabilize its synaptic connections in relation to lower rather than higher spatial frequencies, and therefore emerge as the result of the combined effect of perceptual constraints that may be lead back to the properties of the infant's visual processing system (de Schonen & Mathivet, 1989).

Provided evidence firmly support the idea that non-specific constraints of the newborns' visual system (CSF) combined with peculiar visuo-perceptual characteristics of the face stimuli (LSF) force newborns to process those aspects of a face that deal with large scale variations rather than subtle variations provided by fine details.

Non-specific constraints of the perceptual system interacting with certain systematic variations present in the surrounding environment may thus allow increasing neuro-cognitive specialization of face processes with development. This is in agreement with a cognitive neuroscience perspective that considers domain-specific cognitive structures as emerging gradually from the interaction between tiny innate constraints and the structure of the input provided by the species-typical environment (Elman et al., 1996). In this view, face specialization appears as the product of gradual developmental processes, rather than inherently present at birth. Hence, general experience-expectant sensory and learning mechanisms are considered sufficient to explain the development and attunement of a domain-specific cognitive competence.

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